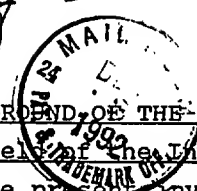


Keywords: child sexual abuse; disclosure; social support

3041

443.00
201A



07985617

1 BACKGROUND OF THE INVENTION

2 1. Field of the Invention

3 The present invention relates to laser ophthalmic
4 surgery using a refractive laser and is concerned with
5 compact, low-cost, low-power laser systems using a
6 computer-controlled, non-contact process and corneal
7 topography to perform corneal reshaping using either
8 surface ablation or thermal coagulation.

9 2. Prior Art

10 Various lasers have been used for ophthalmic
11 applications including the treatments of glaucoma,
12 cataract and refractive surgery. For the
13 non-refractive treatments (glaucoma and cataract), the
14 suitable laser wavelengths are in the ranges of
15 visible to near infrared. They include : Nd:YAG (1064
16 nm), doubled-YAG (532 nm), argon (488, 514 nm).
17 krypton (568, 647 nm), semiconductor lasers (630-690
18 nm, 780-860 nm) and tunable dye lasers (577-630 nm).
19 For refractive surgeries (or corneal reshaping),
20 ultraviolet(UV) lasers (excimer at 193 nm and
21 fifth-harmonic of Nd:YAG at 213 nm) have been used for
22 large area surface corneal ablation in a process
23 called photorefractive keratectomy (PRK). Corneal
24 reshaping may also be performed by laser thermal
25 coagulation currently conducted with Ho:YAG lasers
26 using a fiber-coupled, contact-type process. However,
27 the existing ophthalmic lasers as above described have
28 one or more of the following limitations and
29 disadvantages: high cost (due to the high-power
30 requirement in such as UV lasers for photorefractive
31 keratectomy, large size and weight, high maintenance
32 cost and gas cost (for excimer laser), and high
33 fiber-cost (for contact-type laser coagulation).

008060-7443060

In light of the above, it is an object of the present invention to provide ophthalmic laser systems which offer the advantages of: low-cost, reduced size and weight, reliable, easy-operation and maintenance. Another object of this invention is to provide a computer-controlled scanning device which enables use of a low-cost, low-energy lasers for photorefractive keratectomy currently performed only by high-power UV lasers.

It is yet another object of the present invention to provide a refractive laser system which is compact, portable and insensitive to environmental conditions (such as vibration and temperature). This portable system may also be used for a mobile clinical center where the laser is transported by a van. It is yet another objective of the present invention to provide a non-contact process for corneal reshaping using laser thermal coagulation, where predetermined corneal correction patterns are conducted for both spherical and astigmatic changes of the corneal optical power.

There are several prior art U.S. Patents relating to the refractive surgery, or photorefractive keratectomy. A UV solid-state fifth-harmonic of Nd:YAG (or Nd:YLF) laser at 213 nm (or 210 nm), is disclosed in U.S. Pat. No. 5,144,630 by the inventor, J.T. Lin. U.S. Pat. No. 4,784,135 suggests the use of a UV laser with wavelengths less than 200 nm, in particular Argon Fluoride (ArF) laser at 193 nm, for non-thermal photo-ablation process in organic tissue. Devices for beam delivery and methods of corneal reshaping are disclosed in U.S. Pat. No. 4,838,266 using energy attenuator, and U.S. Pat. No. 5,019,074 using an erodible mask. Techniques for corneal reshaping by varying the size of the exposed

1 region by iris or rotating disk are discussed in
2 Marshall et al, "Photoablative Reprofileing of the
3 Cornea Using an Excimer Laser: Photorefractive
4 Keratectomy" Vol. 1, Lasers in Ophthalmology, pp.
5 21-48 (1986). Tangential corneal surface ablation
6 using ArF excimer laser or harmonics of Nd:YAG laser
7 (at 532 and 266 nm) was disclosed in U.S. Pat. No.
8 5,102,409.

9 This prior art however requires high UV energy of
10 (30-40) mJ per pulse delivered onto the corneal
11 surface, where large area corneal ablation using a
12 beam spot size of about (4-6) mm which gives an energy
13 density of (120-200) mJ/cm². Moreover, the prior art
14 Argon Fluoride excimer lasers operate at a repetition
15 rate of (5-15) Hz and also limit the practical use of
16 the tangential ablation concept which takes at least
17 (5-10) minutes for a -5 diopter corneal correction in
18 a 5-mm optical zone. The high energy requirement of
19 the currently used Argon Fluoride excimer laser
20 suffers the problems of: high-cost (in system,
21 erodible mask and gas cost), high-maintenance cost,
22 large size/weight and system are sensitive to
23 environmental conditions (such as temperature and
24 moisture).

25 One of the essential feature of the present
26 invention for the photorefractive keratectomy process
27 is to use a scanning device in a laser system which
28 has high repetition rates, 50 to 50,000 Hz, but
29 requires less energy, ~~ranging between 0.05-10 mJ~~ per
30 pulse. This new concept enables one to make the
31 refractive lasers at a lower cost, smaller size and
32 with less weight (by a factor of 5-10) than that of
33 prior art lasers. Furthermore, these compact lasers

000000-000000

1 of the present invention are portable and suitable for
2 mobile clinical uses. To achieve beam uniformity and
3 fast refractive surgery (30 to 60 seconds), a
4 mathematical model of the beam overlap and ablation
5 speed is also disclosed in the present invention.

6 For the laser thermokeratoplasty (LTK) process,
7 the prior art uses fiber-coupled contact-type
8 procedure which involves the following drawbacks: (i)
9 slow processing speed (typically a few minutes to
10 perform eight-spot coagulation) which causes the
11 non-uniform collagen shrinkage zone; (ii) circular
12 coagulation zone which limits the procedure only for
13 spherical type correction such as hyperopia; and (iii)
14 the contact fiber-tip must be replaced in each
15 procedure.

16 In the present invention, a computer-controlled
17 scanning device is able to perform the laser
18 thermokeratoplasty procedure under a non-contact mode
19 and conduct the procedure many times faster than that
20 of the prior contact-procedure and without cost for a
21 fiber-tip replacement. Furthermore the coagulation
22 patterns can be computer predetermined for specific
23 applications in both spherical and astigmatic
24 corrections. The flexible scanning patterns will also
25 offer uniform and predictable collagen shrinkage.

26 For ophthalmic applications, it is another
27 objective of the present invention to include but not
28 limited to photorefractive keratectomy, laser
29 thermokeratoplasty, epikeratoplasty, intrastroma
30 photokeratectomy (IPK) and phototherapeutic
31 keratectomy (PTK).

75
17
7
ORIGINAL DOCUMENT

1 SUMMARY OF THE INVENTION

2 Toward this end and according to the present
3 invention, the preferred embodiments of the basic
4 laser system for the ophthalmic surgery process
5 includes the following systems: (1) a diode-pumped
6 solid-state lasers of Nd:YAG or Nd:YLF which is
7 frequency-converted by nonlinear crystals of KTP
8 (potassium titanyl phosphate), LBO (lithium
9 triborate), KNbO₃ (potassium niobate) and BBO (beta
10 barium borate) into the fifth-harmonic at wavelength
11 of 213 nm or 210 nm with energy of 0.01 to 0.05 mJ;
12 (2) a compact, low-cost, low-power (energy of 1 to 10
13 mJ per pulse) argon fluoride excimer laser at 193 nm;
14 (3) a frequency-converted diode-laser at (193-215) nm;
15 (4) a compact, low-cost, Q-switched Er:YAG laser at
16 2.94 microns; and (5) a free-running Ho:YAG (at 2.1
17 microns) or Er:glass (at 1.54 microns).

18 According to one aspect of the present invention,
19 the above-described basic lasers includes UV-lasers
20 (193-215 nm) and IR-laser ^{2.5-3.2}~~(2.94 microns)~~ which are
21 focused into a spot size of ^{0.05-1}~~(0.1-2)~~ mm in diameter,
22 where laser energy per pulse of (0.01-10) mJ is
23 sufficient to achieve the photo-ablation threshold
24 (PAT) energy density of 50 to 160 mJ/cm² depending upon
25 the laser parameters (wavelengths and pulse duration)
26 and tissue properties (absorption and scattering).
27 The prior art excimer laser uses large beam spot
28 ablation (4-6 mm) and require much higher laser energy
29 (30-40 mJ) than the low-power lasers presented in this
30 invention. In the present invention, a scanning,
31 non-contact device is used to control the low-power
32 laser for corneal diopter change, whereas diaphragm or
33 mask are used in the high-power, high-cost excimer

1 without causing problems of corneal haze and
2 corrective regression. Real corneal tissues may also
3 be sculpted and implanted by the above-described laser
4 systems, a procedure known as laser myopic
5 keratomileusis (MKM). Furthermore the UV and IR lasers
6 disclosed in the present invention provide an
7 effective tool for phototherapeutic keratectomy (PTK)
8 which is currently conducted by high-power excimer
9 lasers and the procedure conducted by diamond-knife
10 called radial keratotomy (RK). This procedure
11 conducted by UV or IR lasers is called laser
12 radial keratotomy (LRK). The fundamental beam at 1064
13 or 1053nm wavelength of the present invention may also
14 be used for the intrastroma photorefractive
15 keratectomy (IPK), where the laser beam is focused
16 into the intrastroma area of the corneal and collagen
17 tissue are disrupted.

18 To summarize, the ophthalmic applications of the
19 laser systems described in the present invention
20 should include but not limited to: photorefractive
21 keratectomy, phototherapeutic keratectomy, laser
22 thermokeratoplasty, intrastroma photokeratectomy,
23 synthetic epikeratoplasty, and laser radial
24 keratotomy.

25 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of computer-controlled refractive laser system consisting of the basic laser, scanning device, power supply and the beam steering stage for ophthalmic applications;

Fig. 2 is a block diagram for the generation of ultraviolet wavelengths at 213 nm or 210 nm using nonlinear crystals in a diode-pumped system;

Fig. 3 is a block diagram of a computer-controlled refractive laser system of Ho:YAG or Er:glass in a non-contact scanning mode for laser thermokeratoplasty;

5 Figs. 4A through 4E shows computer-controlled
6 scanning patterns for photo-coagulation in non-contact
7 LTK procedures for both spherical and astigmatic
8 corneal reshaping;

9 Figs. 5A and 5B are procedures for laser-assisted
10 myopic keratomileusis and hyperopic keratomileusis,
11 where the reshaping can be performed either on the
12 inner or outer part of the tissue;

13 Figs. 6A through 6D show computer-controlled beam
14 overlap and scanning patterns for myopic, hyperopic
15 and astigmatic correction using UV (193, 210, 213 nm)
16 or IR (2.15-3.2 microns) lasers;

17 Figs. 7A and B are laser radial keratectomy
18 patterns (LRK) using laser excisions for myopia
19 (radial-cut) and astigmatism (T-cut); and

20 Figs. 8A through 8D shows ablation patterns for
21 refractive correction using predetermined coatings on
22 UV or IR grade windows.

23 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

24 The theoretical background of the present invention
25 with regards to the beam overlap and ablation rate in
26 photorefractive keratectomy, intrastroma
27 photokeratectomy, synthetic epikeratoplasty,
28 phototherapeutic keratectomy and myopic keratomileusis
29 procedures described in the present invention is as
30 follows. Portions of the theoretical background was
31 published by the inventor, J. T. Lin, in SPIE Pro. vol
32 1644, Ophthalmic Technologies II (1991), p.p. 266-275.

$$1 \quad h(x) = h_0 + 1.32DW^2 \quad (1)$$

$$2 \quad h_0 = -0.3315DW^2 \quad (2)$$

3 In a scanning system as disclosed in the present
4 invention, the number of ablation layers (M1) (without
5 beam overlap) required for D-diopter correction is
6 therefore related to the ablation thickness per pulse
7 (T1), D, and W by

$$8 \quad M1 = h_0/T1 = -0.3315DW^2/T1 \quad (3)$$

9 To include the overlap factor (F), F=2 for a 50% beam
10 overlap scan and F=5 for 80% overlap, the required
11 effective number of overlapped ablation layers is
12 M1/F.

13 For a given ablation zone of W and laser focused
14 spot area of A, one requires an effective single-layer
15 scanning time (TS) of FW^2/A .

16 The total operation time (T) needed for h0 center
17 ablation or D-diopter correction becomes

$$18 \quad T \propto (M1/F)(TS) \quad (4) \\ \propto DW^4/E$$

19 Equation 4 gives us the scaling-law for operation
20 time required (T), the laser energy (E), diopter
21 change (D) and the ablation zone diameter (W). For a
22 given laser energy per pulse of E, the overall
23 operation rate (1/T) is independent to the laser
24 intensity (I) and beam spot size (A). By increasing
25 the laser average-power (P), defined by laser
26 energy/pulse X repetition rate, more total energy may
27 be delivered to the cornea per unit time. The
28 average-power (P) is the key factor which actually

1 determine the overall operation rate (or time)
2 required to achieve the diopter change. By realizing
3 that the scanning rate (1/TS) is proportional and
4 synchronized to the laser repetition rate (RP), we are
5 able to re-express Eq. (4) as

6 $T \propto DW^4/P$ (5).

7 It is important to note that given an
8 average-power of P, the laser intensity must be above
9 the photo-ablation threshold(PAT) by either beam
10 focusing or increase the laser energy (~~fluency per~~
11 ~~pulse~~).

12 Based upon the above-described theory, we are able
13 to summarize some important features accordingly: (i)
14 CW lasers (either UV or IR) with low intensity
15 normally can not cause photo-ablation since the energy
16 density is lower than the PAT value; (ii) Lasers (UV or
17 IR) at ~~Q-switched mode~~ and with pulse-duration shorter
18 than ~~100~~ ¹⁰ nanosecond will normally achieve the
19 intensity above the PAT even at low-energy level of
20 0.05-5 mJ. In particular, ¹⁰ picosecond lasers at high
21 repetition rate would be one of the favor candidates,
22 where energy in the micro joule range would be
23 sufficient. Moreover, the Q-switched short pulse
24 lasers have smaller thermal damage than that of
25 free-running lasers. The cost-effective refractive
26 lasers shall be those which have high repetition rates
27 (50 Hz and up) but operated at low-energy (^{0.001-20} ~~0.05-5~~ mJ)
28 and short pulse duration (^{0.01-100} ~~0.01-100~~ nanoseconds). The
29 preferred embodiments disclosed in the present
30 invention as discussed in Fig. 1 are based upon this
31 theory behind. Beam focusing and scanning are always
32 required to achieve the PAT and smooth ablation

1 profile. We also note that the individual beam profile
2 in the scanning system is not as critical as that of
3 the prior art lasers which require a uniform overall
4 profile within the large ablation zone of (4-6) mm.
5 In our laboratory we have achieved very smooth
6 ablation profile with zone diameter up to 8 mm
7 starting from a non-uniform focused beam profile which
8 were randomly scanned over the ablation zone of (1-8)
9 mm. Using overlap of (50-80)% of focused beam spot of
10 (0.5-1) mm, typical number of pulses delivered to the
11 corneal surface is (1,000-2,000) which assures the
12 sufficient beam overlap for smooth profile and
13 pulse-pulse energy fluctuation is not critical.

Referring to Fig. 1, a refractive laser system in accordance with the present invention comprises a basic laser 10 having UV (193 nm, 213 nm or 210 nm) or IR (2.94 microns) wavelength 11 coupled by a scanning device 12 having the beam from focusing optics 14 directed onto a reflecting mirror 15 into target 16 which target may be the cornea of an eye. An arming system 17 has a visible wavelength (from a laser diode or He-Ne laser) 18 adjusted to be collinear with the ablation beam 11 and defines the centration of the beam onto the cornea surface at normal incident. The basic laser head 20 is steered by a motorized stage for X and Y horizontal directions 21 and the vertical (height) direction 22 which assures the focusing beam spot size and the centration of the beam onto the cornea. The system has a computer controlled panel 23 and wheels 24 for portable uses. The target 16 includes a human cornea for applications of photorefractive keratectomy, phototherapeutic keratectomy and laser radial keratotomy (using the UV 193, 210, 213 nm or IR 2.9 microns beam focused on the

000000 1-11-77 130000

1 corneal surface area) and intrastroma photokeratectomy
2 (using the 1064 or 1053 nm beam, or their
3 second-harmonic, focused into the intrastroma area),
4 and synthetic or real corneal tissues for applications
5 of synthetic epikeratoplasty and myopic
6 keratomileusis. The computer controlling panel 23 also
7 provides the synchronization between the scanning gavo
8 and the laser repetition rate. A commercially
9 available galvanometer scanner made by General
10 Scanning, Inc. is used in scanning the laser beam.

11 The laser systems described herein have been
12 demonstrated using photorefractive keratectomy
13 procedure with a diopter corrections up to -12 in PMMA
14 plasty and -6 in corneal tissues. In the case of PMMA
15 we have also measured the diopters by a ^{lensometer} lens meter
16 with well-defined readings in the ranges of -1 to -12
17 diopters. This data provides the evidence of
18 predictable diopter corrections using the laser
19 systems of the present invention. Furthermore,
20 minimal tissue thermal damage of 0.3-1.0 microns were
21 measured by TEM (transmission electron microscopy). In
22 my measurements, I used the multi-zone (MZ) approach
23 for high-diopter corrections (8-12), where the
24 center zone is 3 mm and the correction power decreases
25 when the zone increases from 4 mm to 6 mm. This multi-
26 zone approach reduces the overall ablation thickness
27 and hence reduces the haze effect.

28 Still referring to Fig. 1, the basic laser is
29 according to the present invention includes a compact,
30 optically-pumped (either flash-lamp or laser-diode
31 pumped) lasers of Nd:YAG, Nd:YLF or the
32 self-frequency-doubling crystal of NYAB (neodymium
33 yttrium aluminum) with pulse duration of 0.05-20
34 nanoseconds and repetition rate of 1-10,000 Hz. It is

000000-FT-48060

1 The low-power laser systems described in the
2 present invention can perform the procedures normally
3 required in high-power systems because a scanning
4 device is used to assure the uniform corneal ablation
5 by beam overlap and the ablation threshold is
6 achievable when small spot size is used even in a
7 low-energy system.

8 Referring to Fig. 2, a preferred embodiment for
9 the basic laser 10 of Fig. 1 having a UV wavelength
10 includes a diode-pumped Nd:YAG (or Nd:YLF) 25 having
11 a fundamental wavelength of 1064 nm (or 1053 nm) 26
12 and is focused by a lens 27 into a doubling crystal 28
13 (KTP, KNbO₃, LBO or BBO) to generate a green
14 wavelength 30 at 532 nm (or 527 nm). The green beam
15 30 is further converted by a fourth harmonic crystal
16 31 (BBO) to generate a UV wavelength 32 at 266 nm (or
17 263 nm) which is finally converted by a fifth harmonic
18 crystal 33 to generate the UV wavelength 11 at 213 nm
19 (or 210 nm). From a commercially available
20 diode-pumped Nd:YLF laser I am able to achieve the UV
21 (at 210 nm) energy of 0.01-0.05 mJ per pulse with
22 average-power of 50 to 150 mW. This energy level when
23 focused into a spot size of $(\frac{0.05-0.5}{0.1-0.2})$ mm is sufficient
24 to ablate the corneal tissue. This diode-pumped
25 fifth-harmonic system provides the most compact
26 refractive UV solid-state laser available today with
27 the advantages of long lifetime, low maintenance,
28 portability and absence of toxic gas in comparison
29 with the excimer lasers currently used by other
30 companies, such as Summit Technology, Inc. and Visx
31 Inc. Furthermore by using the fundamental wavelength
32 at 1064 nm (or 1053 nm) or their second-harmonic (at
33 532 or 527 nm), intrastroma photokeratectomy procedure
34 may be performed by focusing the beam into the

intrastroma area of the cornea. The laser presented in the present invention provide a compact, portable and low-cost IPK laser and has an advantage over the lasers used by other companies, such as Phoenix Laser Systems Inc. and Intelligent Surgical Lasers, Inc., where the systems are currently more than five times heavier and are more costly.

In Fig. 3, a commercially available Ho:YAG (or Er:glass) laser 35 (either flash-lamp or laser-diode pumped) is coupled by a fiber optic waveguide 36 with core diameter of (100-600) microns to a scanning device 37, in which the fundamental beam 38 with a wavelength of 2.1 (or 1.54) microns which is collimated by a lens 40 and coupled to the scanning gavo 41 and focused by another lens 42 onto the beam splitters 43 and 44, and finally delivered to a target (such as a patent's corneal) 45. The IR (2.1 microns) laser beam 38 is collinear with the aiming beam 46 (visible He-Ne or diode laser) and the patent corneal center is also defined by a commercial slit-lamp microscope station 47. The above-described apparatus offers the unique feature of non-contact laser thermokeratoplasty for precise coagulation in both spherical and astigmatic corneal power corrections with scanning patterns predetermined by a computer software hereinafter discussed. The focusing lens 28 may be motorized for varying the focal point and thus varying the coagulation cone size for optimal results.

In the prior art of fiber-tip contact system, the precision of the coagulation zone and patterns are limited by doctors manual operation which is a much slower procedure than the computer controlled scanning device described in the present invention. The requirement of replacing the fiber-tip after each

1 operation is also a drawback of the prior art systems.
2 The advantages of the present system includes:
3 precision coagulation zone and spot size, flexible
4 patterns for a variety of corrections, fast processing
5 time and elimination of the need for fiber-tip
6 replacement.

7 Still referring to FIG. 3, the basic laser 22 in
8 accordance with the preferred embodiment of the
9 present invention is a free-running or continuous-wave
10 (CW) flash-lamp or diode-laser pumped Ho:YAG (at 2.1
11 microns) or Er:glass (at 1.54 microns), with average
12 power of 0.2-10 W, pulse duration of 200-2,000
13 micro-seconds (if free-running). In the present
14 invention, the IR wavelengths of 1.54 and 2.1 microns
15 are chosen due to their strong tissue absorption which
16 is required in the photo-coagulation processes.
17 Similar lasing media of Ho:Tm:YAG and Ho:Tm:Cr:YAG is
18 also included in the preferred embodiments of the
19 present invention.

20 Figs. 4A through 4E summarize the possible
21 coagulation patterns suitable for both spherical and
22 astigmatic corneal reshaping in the LTK procedures in
23 a cornea 50. Fig. 4-A with coagulation zone (CZ) of 5
24 to 9 mm and spot number (SN) of (8-16) provides
25 hyperopic corrections of 1-6 diopters; Fig. 4-B has a
26 coagulation zone of 1-3 mm suitable for myopic
27 corrections; Fig. 4-C has radial coagulation zone and
28 spot number of 16-32, suitable for spherical hyperopic
29 correction; Fig. 4-D has a coagulation zone of 1-9 mm
30 and spot number of 50-200, suitable for precise
31 coagulation control to stabilize and reinforce the
32 collagen shrinkage tension; Fig. 4-E is designed for
33 astigmatic change, where the coagulation patterns are
34 chosen according to the corneal topography. By using

1 illustrated in Fig. 4. which can be easily performed
2 in the computer-controlled scanning device as
3 disclosed in the present invention. The patient's eye
4 motion and decentration is a problem for the prior art
5 systems, but it is not a critical factor in the fast
6 scanning device described herein.

7 Referring to Fig. 5, a laser-assisted myopic
8 keratomileusis (MKM) and hyperopic keratomileusis
9 (HKM) can be performed either on the outer corneal
10 surface 51 or on the inner surface 52 to reshape the
11 resected corneal tissue without materially effecting
12 Bowman's layer. The preferred lasers are described in
13 Fig. 1 including the UV (193-215 nm) and IR (2.94
14 microns) lasers. The non-invasive laser-assisted
15 procedure disclosed in the present invention has the
16 advantages over the procedures of photorefractive
17 keratectomy and laser thermokeratoplasty including
18 being safer, more stable with a higher diopter change,
19 and without materially affecting epithelium and
20 Bowman's layer. In comparison with the conventional
21 keratomileusis, the laser-assisted myopic
22 keratomileusis and hyperopic keratomileusis do not
23 require corneal freezing and can perform very high
24 diopter change not available by radial keratotomy or
25 photorefractive keratectomy. Laser-assisted corneal
26 preshaping can also be employed for a donor cornea in
27 the procedure currently performed by epikeratophakia.
28 Details of conventional lamellar refractive surgery
29 may be found in Leo D. Bores, Refractive Eye Surgery
30 (Blackwell Scientific Pub., 1993), Chapter 10.

31 Figs. 6A through 6D shows a nearly flat-top beam
32 profile achieved by overlapping a series of laser
33 beams, where the degree of overlap, 50%-60%, depends
34 on the individual beam profiles which are not required

1 to be flat-top. In the present invention, the
2 preferred individual beam profile is either a 70%
3 Gaussain or a smooth symmetric profile. In the
4 laboratory, I have demonstrated a smooth laser-ablated
5 corneal surface with zone diameter of 3-6 mm by
6 overlapping a large number of pulses, 500 to 2,000,
7 each one having a spot size of 0.8-1.2 mm. Moreover
8 smooth transition among the ablation zones were
9 achieved without the transition zone steps found in
10 prior art systems using mechanical diaphragms. In
11 addition to the myopic and hyperopic scanning patterns
12 of 6B and 6C, one of the significant features of the
13 present scanning device is that it can generate
14 predetermined patterns based upon the corneal
15 topography for astigmatism correction (see 6D).
16 Corneal scar may also be easily located by a
17 topography and photoablated by a laser based on the
18 computer-controlled scanning patterns. The preferred
19 lasers for the procedures described in Fig. 6 are
20 discussed in connection with Fig. 1.

21 Still referring to Fig. 6, the scanning schemes
22 were tested by ablation on PMMA plasty. The computer
23 software is based upon the mathematical model
24 described earlier where the center ablation thickness,
25 see equation (2), was equally spaced to define the
26 associate scanning diameters. Given the ablation
27 thickness per pulse and per ablation layer (at a given
28 scanning diameter), one may easily obtain the overall
29 corneal surface ablation profile, see equation (1).
30 The numbers of required ablation layer is therefore
31 proportional to the diopter change (D) and square of
32 the ablation zone (W). The computer parameters
33 designed in the present invention include: diopter
34 change (d), optical zone diameter (W), and the degrees

000000-1111111111

1 used circular scanning patterns with beam overlap
2 controlled by the tangential scanning speed and
3 diameters of the adjoined circles. The preferred
4 scanning scheme is from small circle to large circle.
5 For example, given a laser spot size of 1 mm, a radial
6 overlap of 50% will require the scanning circle to
7 start from 1 mm diameter to 5 mm diameters with an
8 increment of 0.5 mm for an optical zone of 5 mm.
9 Furthermore, a tangential overlap of 50% will require
10 the scanner to move at an angular speed of about 23
11 degrees within the interval between each laser pulse.
12 In my computer-controlled scanning device, software
13 was developed to synchronize the laser repetition rate
14 with the scanning gavo to control the above-described
15 overlap patterns. In addition to the circular
16 patterns described for myopic and hyperopic
17 treatments, a linear scanning pattern was used in
18 particular for the astigmatic correction, where
19 angular speed with uniform overlap would be difficult
20 to achieve in a circular pattern.

21 It is important to note that a uniform individual
22 beam profile and energy stability of the laser, under
23 our scanning device, are not critical in achieving an
24 overall uniform ablation zone whereas they are very
25 critical for the prior art systems using expanding
26 iris devices. Given the ablation rate per overlapped
27 circle, the overall diopter correction may be achieved
28 by the appropriate increment in diameters of the
29 expanding circles.

30 Referring to Figs. 7A and 7B, a laser radial
31 keratectomy (LRK) performed by laser excision has
32 advantages over the conventional diamond-knife radial
33 keratotomy (RK) including higher predictability and
34 reproductability by precise control of the excision

11/22/77

[illegible]

1. A method of performing laser surgery on the eye comprising the steps of:
- selecting a scanning pulsed laser having an output laser beam of a predetermined frequency;
 - coupling said output laser beam to selected focusing optics for focusing said output laser beam;
 - directing said focused output laser beam in a predetermined overlapping scanning beam path with repetitive pulses onto a plurality of positions on a patient's eye, whereby a portion of a patient's eye is ablated at predetermined positions for correcting the patient's vision.
2. A method of performing laser surgery on the eye in accordance with claim 1 including the step of positioning said scanning laser focusing optics a predetermined distance from the surface of the patient's eye for scanning said patient's eye.
3. A method of performing laser surgery on the eye in accordance with claim 2 in which the step of selecting a scanning laser includes selecting a diode pumped UV laser having an output wavelength between 193 and 215 nanometers.
4. A method of performing laser surgery on the eye in accordance with claim 2 in which the step of selecting a scanning laser includes selecting an excimer laser having a UV output wavelength of 193 nanometers.

1 5. A method of performing laser surgery on the
2 eye in accordance with claim 2 in which the step of
3 selecting a scanning laser includes selecting a free-
4 running ER:glass laser having an output wavelength of
5 1.54 microns.

1 6. A method of performing laser surgery on the
2 eye in accordance with claim 2 in which the step of
3 selecting a scanning laser includes selecting a Ho:YSG
4 laser having an output wavelength of 2.1 microns.

1 7. A method of performing laser surgery on the
2 eye in accordance with claim 2 in which the step of
3 selecting a scanning laser includes selecting a Q-
4 switched ER:YAG laser having an output wavelength of
5 2.94 microns.

1 8. A method of performing laser surgery on the
2 eye in accordance with claim 2 in which the step of
3 selecting a scanning laser includes selecting a said
4 scanning laser having an output of 0.01-10 mJ.

1 9. A method of performing laser surgery on the
2 eye in accordance with claim 8 in which the step of
3 selecting a scanning laser includes selecting a said
4 scanning laser having a repetition rate of between 1-
5 10,000 pulses per second.

1 10. A method of performing laser surgery on the
2 eye in accordance with claim 9 in which the step of
3 selecting a scanning laser includes selecting a
4 scanning laser having an output beam pulse duration of
5 between 0.05 nanoseconds and five hundreds of a micro-
6 second.

21. A method of photo-ablating and photo-coagulating a portion of the cornea of the eye for reshaping the cornea comprising the steps of:

- selecting a scanning laser having a laser beam of a predetermined frequency;
- selecting a laser scanning mechanism for scanning said selected laser beam;
- selecting focusing optics for focusing said output laser beam;
- positioning said focusing optics a predetermined distance from a patient's eye for scanning the eye with said laser beam without physical contact with the eye;
- directing said focused laser beam in a predetermined overlapping scanning beam path onto a patient's eye with said selected laser scanning mechanism, whereby a portion of a patient's eye is ablated or coagulated using a low power laser beam having repetitive beam patterns applied at predetermined positions for correcting a patient's vision.

22. A method of photo-ablating a portion of the cornea of the eye for reshaping the cornea in accordance with claim 21 in which the step of selecting a scanning laser includes selecting a scanning laser having a circular scanning pattern for delivering uniform laser energy over repeated circular scans.

008060 7444060

1 23. A method of photo-ablating a portion of the
2 cornea of the eye for reshaping the cornea in
3 accordance with claim 21 in which the step of
4 selecting a scanning laser includes selecting a
5 scanning laser having a plurality of circular scanning
6 patterns for delivering uniform laser energy over
7 repeated circular scans.

1 24. A method of photo-ablating a portion of the
2 cornea of the eye for reshaping the cornea in
3 accordance with claim 21 including the step of
4 selecting a coated window for directing said laser
5 beam therethrough and onto the cornea of a patient's
6 eye.

1 25. A method of photo-ablating a portion of the
2 cornea of the eye for reshaping the cornea in
3 accordance with claim 24 including the step of
4 selecting a coated window of a UV grade fused silica
5 for directing said laser beam therethrough and onto
6 the cornea of a patient's eye.

1 26. A method of photo-ablating a portion of the
2 cornea of the eye for reshaping the cornea in
3 accordance with claim 24 including the step of
4 selecting a coated window of a sapphire for directing
5 an IR laser beam therethrough and onto the cornea of
6 a patient's eye.

1 27. A method of photo-ablating a portion of the
2 cornea of the eye for reshaping the cornea in
3 accordance with claim 24 including the step of
4 selecting a coated window of BaF for directing said
5 laser beam therethrough and onto the cornea of a
6 patient's eye.

[illegible]

OPHTHALMIC SURGERY METHOD USING
NON-CONTACT SCANNING LASER

ABSTRACT

A refractive laser surgery process is disclosed for using compact, low-cost ophthalmic laser systems which have computer-controlled scanning with a non-contact delivery device for both photo-ablation and photo-coagulation in corneal reshaping. The basic laser system may include flash-lamp and diode pumped UV lasers (193-215 nm), compact excimer laser (193 nm), free-running Er:glass (1.54 microns), Ho:YAG (2.1 microns) and Q-switched Er:YAG (2.94 microns). The advantages of the non-contact, scanning device used in the process over other prior art lasers include being safer, reduced cost, more compact and more precise and with greater flexibility. The theory of beam overlap and of ablation rate and coagulation patterns is also disclosed for system parameters. Lasers are selected with energy of (0.01-10) mJ, repetition rate of (1-10,000), pulse duration of 0.05 nanoseconds to a few hundreds of a micro-second, and with spot size of (0.1-2) mm for use with various refractive laser surgery.

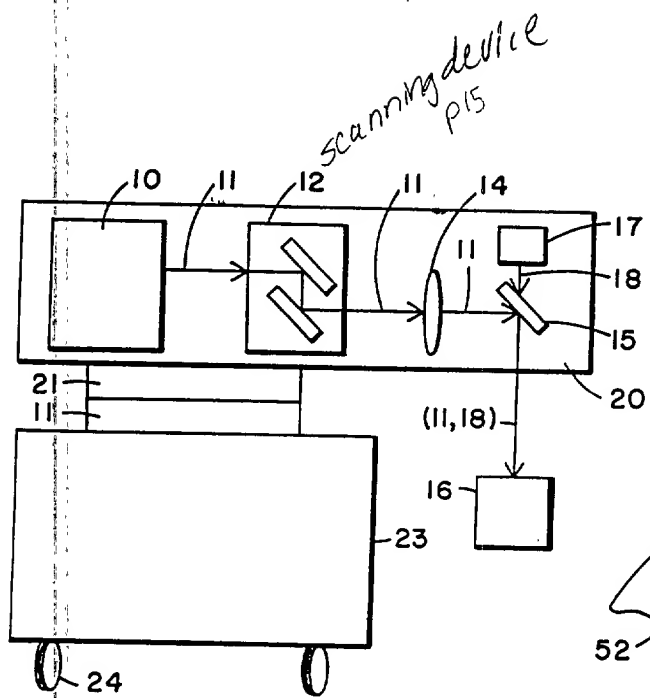


FIG. 1

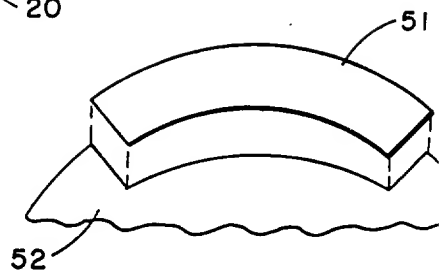


FIG. 5A

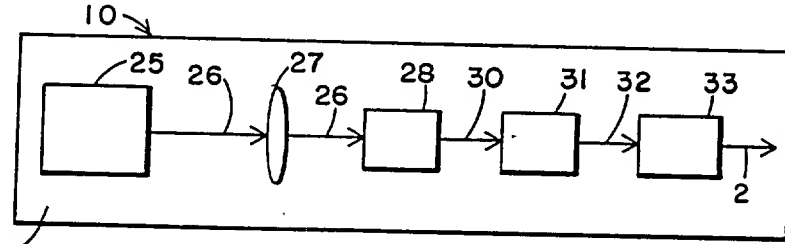


FIG. 2

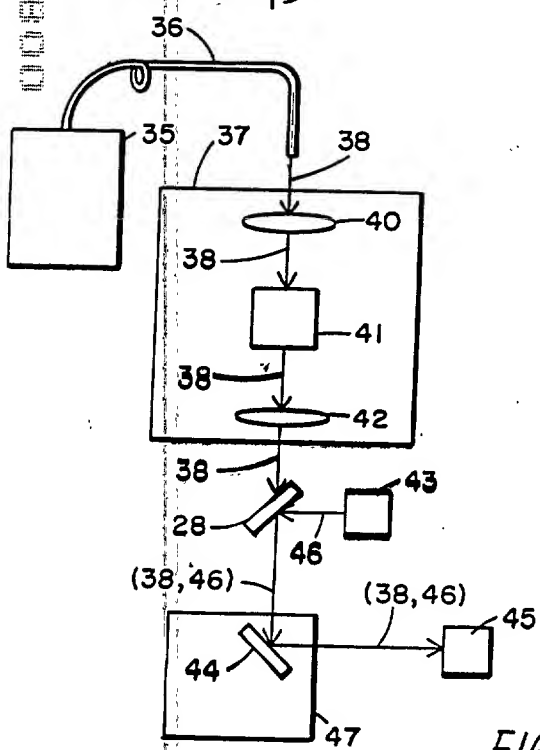


FIG. 3

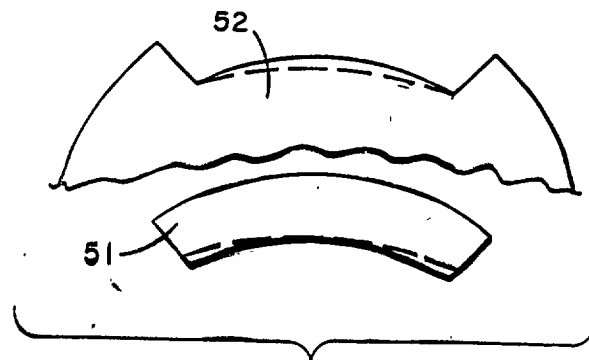


FIG. 5B

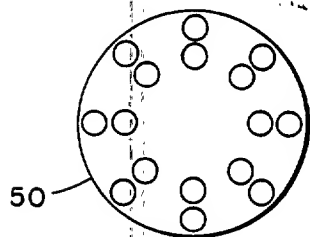


FIG. 4A

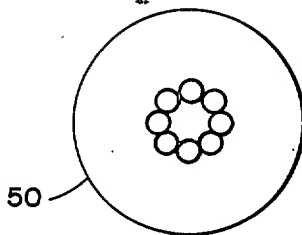


FIG. 4B

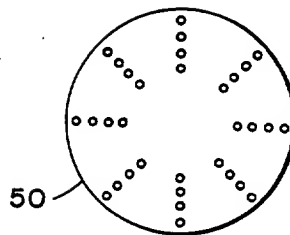


FIG. 4C

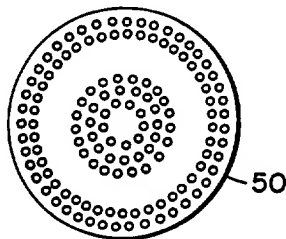


FIG. 4D

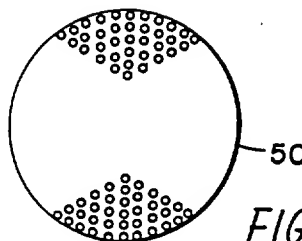


FIG. 4E

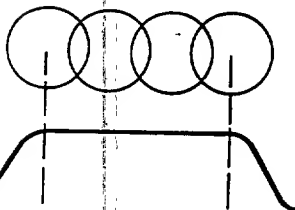


FIG. 6A

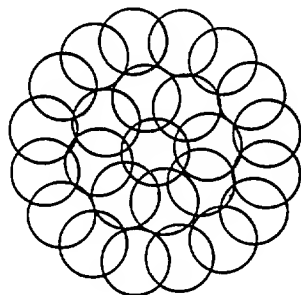


FIG. 6B

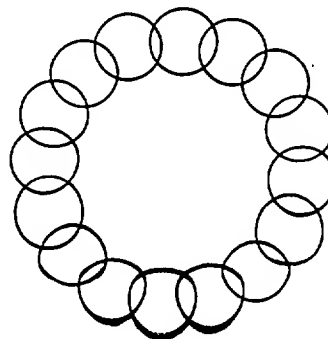


FIG. 6C

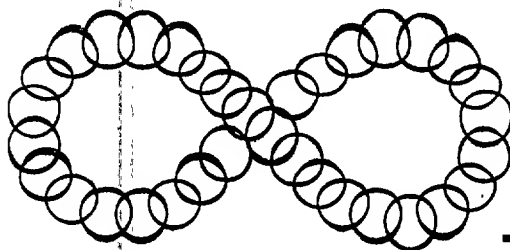


FIG. 6D

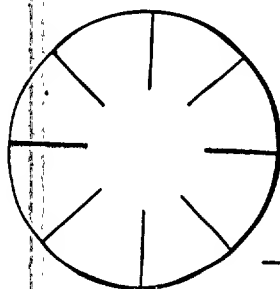


FIG. 7A

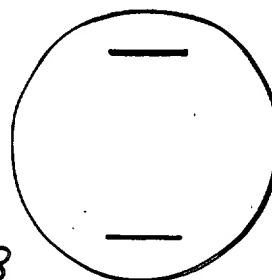


FIG. 7B

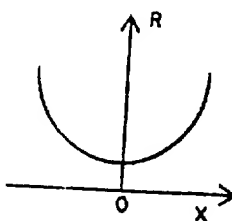
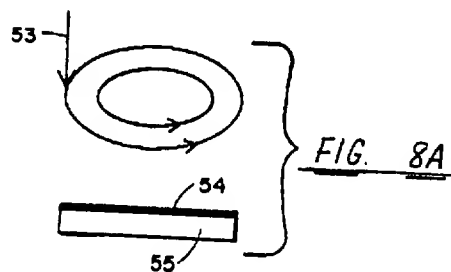


FIG. 8B

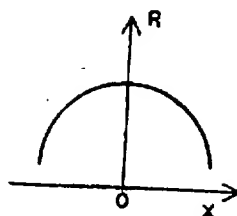


FIG. 8C

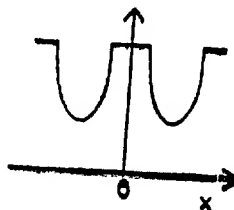


FIG. 8D

FILING RECEIPT



UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
ASSISTANT SECRETARY AND COMMISSIONER
OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

| APPLICATION NUMBER | FILING DATE | GRP ART UNIT | FIL FEE REC'D | ATTORNEY DOCKET NO. | DRWGS | TOT CL | IND CL |
|--------------------|-------------|--------------|---------------|---------------------|-------|--------|--------|
| 09/084,441 | 05/27/98 | 3736 | \$1,655.00 | 62-575 | 5 | 104 | 10 |

020736

FARKAS & MANELLI

2000 M STREET NW SUITE 700

WASHINGTON DC 20036-3307

Receipt is acknowledged of this nonprovisional Patent Application. It will be considered in its order and you will be notified as to the results of the examination. Be sure to provide the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION when inquiring about this application. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. If an error is noted on this Filing Receipt, please write to the Application Processing Division's Customer Correction Branch within 10 days of receipt. Please provide a copy of the Filing Receipt with the changes noted thereon.

Applicant(s)

J. T. LIN, WINTER SPRINGS, FL.

CONTINUING DATA AS CLAIMED BY APPLICANT-

THIS APPLN IS A RE OF 08/218,319 03/25/94 PAT 5,520,679
WHICH IS A CIP OF 07/985,617 12/03/92 ABN

FOREIGN FILING LICENSE GRANTED 11/18/98

* SMALL ENTITY *

TITLE

OPHTHALMIC SURGERY METHOD USING NON-CONTACT SCANNING LASER.

PRELIMINARY CLASS: 606

DATA ENTRY BY: BATES, DIANE

TEAM: 03 DATE: 12/17/98